Metacognitive Tutoring for Scientific Modeling

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Abstract. In this paper, we present a set of metacognitive tutors for teaching scientific inquiry-driven modeling. We describe the MeTA architecture in which the tutors are implemented and experiences with an initial pilot study.

Keywords: metacognitive tutors, intelligent tutoring systems, scientific modeling, middle school science.

1 Introduction

Supporting metacognition has been identified as one of the most important principles of instructional design [4]. In recent years, interventions using a variety of metacognitive skills have been studied. Aleven et al. examine the use of a metacognitive tutor for help seeking within a cognitive tutor for geometry [1]. Some systems, such as MetaTutor, focus on teaching students self-assessment skills to identify knowledge gaps or monitor their own progress [3,10]. Betty's Brain can teach students metacognitive skills by having them request that Betty engage in those skills herself [11]. These projects have shown the success of tutoring interventions based on developing metacognitive skills.

Inquiry-based learning has long been pursued as a desirable approach to classroom curriculum design [6], and significant efforts have been made to incorporate authentic scientific modeling and inquiry into science education, such as in projects like Thinker Tools [13]. This paper presents our early efforts to construct a metacognitive tutoring system specifically aimed at teaching these skills within an open-ended learning environment named MILA (for Modeling & Inquiry Learning Application).

2 Tutoring Scientific Inquiry-Driven Modeling in MILA

MILA (**M**odeling & **I**nquiry **L**earning **A**pplication) is an interactive learning environment for supporting learning about ecosystems in middle school science. Students use MILA to construct Component-Mechanism-Phenomenon models of complex ecological phenomena. Component-Mechanism-Phenomenon models are adaptations of Structure-Behavior-Function models [7,12], and MILA evolves from our earlier work on learning Structure-Behavior-Function models of ecosystems [8,12].

To support students' modeling and inquiry while engaging with MILA, we constructed a metacognitive tutoring system consisting of four separate metacognitive tutoring agents playing four different functional roles: a Guide, a Critic, a Mentor, and an Interviewer. Broadly, these tutors were constructed according to lessons and guidelines transferred from other initiatives in metacognitive tutoring [2,10]. Students interact with tutors by clicking tutors' avatars in the tutor box. Upon clicking, the tutor's window appears and gives the student any feedback it has available, as shown in Figure 2. Reactive tutors checks their Mappings when the student clicks in order to respond to students' help-seeking behaviors [1]. A proactive tutor actively monitor students' progress and interrupt the students to provide their feedback or ask their question in order to facilitate just-in-time error correction [10].

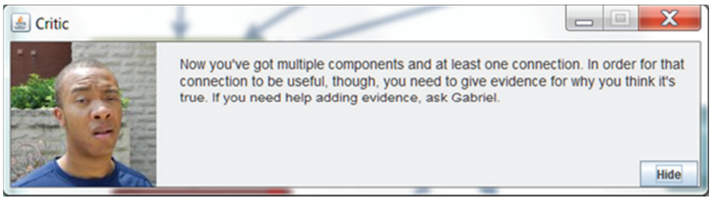

Fig. 2. An example of one of the four tutors, the Critic. All tutors appear in dialog boxes such as this one. In addition to text feedback, tutors may ask students to answer questions or offer students questions they might want answered.

The Guide serves to answer students' questions, and thus is a reactive tutor. She is developed to anticipate what questions students may want to ask based on the current lesson, the students' current model, software, and tutor interactions and then offer those questions when called. For example, early in the unit, the Guide anticipates questions that largely focus on interaction with the software itself. Later, she expects and offers questions based on students' current models or recent model construction process.

The Critic analyzes students' models, validating students' models against a set of defined model criteria. He is a reactive tutor who only checks models when students are looking for feedback, demonstrating the knowledge gaps of which students should be aware in model construction and providing guidance on how to fill those knowledge gaps, as well as avoid them in the future.

The Mentor leverages the notion of cognitive apprenticeship [5]. He is a proactive tutor who observes students' interaction with the software and demonstrates new or difficult concepts. In practice, the main role of the Mentor has been to set expectations and learning goals, addressing Roll et al.'s eighth design principle: communicate the metacognitive learning goals to the students [10].

Completing the set of four tutors is the Interviewer. The Interviewer asks students to answer questions in natural language. The Interviewer serves the metacognitive goal of encouraging students to self-reflect on their process by prompting students to elucidate their decision-making.

3 The Architecture of MeTA

This set of metacognitive tutors for teaching inquiry-driven modeling has been constructed in an experimental architecture titled MeTA, for Metacognitive Tutoring Architecture. At a basic level, the MeTA architecture builds on the characterization of an intelligent agent as a function f that maps a history of percepts P* into an action A; f: $P^* \rightarrow A$. This section describes MeTA at a software architecture level, consisting of percepts, actions, and mappings between them.

Percepts are defined information the tutor can sense in the learning environment. We have used six categories of percepts for constructing our tutors, including history software and tutor interaction and a current model of student behavior. Actions, in turn, are output complements to the input percepts. Whereas percepts tell tutors for what to look for, actions tell them how to respond. We have used six different categories of actions, including textual feedback, soliciting further information, and altering an underlying model of student behavior. Mappings pair up sets of Percepts with sets of Actions. When every Percept in a given Mapping is observed, the tutor responds with the associated Actions. In many ways, individual tutors can be seen as prioritized lists of Mappings.

4 Initial Deployment & Results from MeTA in MILA

MILA was used in a two-week camp in Summer 2012 with 16 middle school students. The phenomenon that students were charged with explaining was the actual, sudden death of thousands of fish in a nearby lake. To investigate this problem, students took field trips to the lake, participated in physical science and biology exercises, and engaged with MILA in groups of two or three. MILA provided facilities for stating the problem, proposing multiple hypotheses, modeling those hypotheses, consulting static simulations, and researching online hypermedia and data sources. Given that this was the first use of MeTA tutors in a classroom, data gathering and analysis was treated as an exploratory study; the goal, in line with design-based research, was to observe the strengths and weaknesses to better understand how to create effective metacognitive tutors in the future. We found two primary guidelines that are informing our ongoing revisions to the tutoring systems. First, our experience deploying tutors that play multiple functional roles within the software directed our attention to the different ways in which students interact with different roles and types of feedback; this has been similarly touched on elsewhere in research on metacognitive tutoring [3,9]. This has led to the revision of these tutors for new interventions to better differentiate their functional roles and expand the range of types of feedback available. Secondly, we observed the need to address the challenge outlined in Roll et al. 2007 [10] regarding applying one of Anderson et al. 1995's original design guidelines [2] to the metacognitive tutoring domain. This principle – "Facilitate successive approximations of the target skill" – addresses the need to differentiate and address the student's current level of efficacy with the target skill, changing the way in which the skill is addressed as student efficacy changes. Ongoing revisions to the tutors outlined here attempt to equip the system with the ability to infer and address successive approximations of the target skill.

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